



## **Fabrication of a lightweight CTE matched optical structure from Be/BeO Metal Matrix Composite**

**Ryan McClelland- NASA  
GSFC/SGT- NGXO Lead Engineer**

**Will Zhang- NASA GSFC NGXO  
Principal Investigator**

**Rob Michel- Materion  
Mgr. Market and Business  
Development**

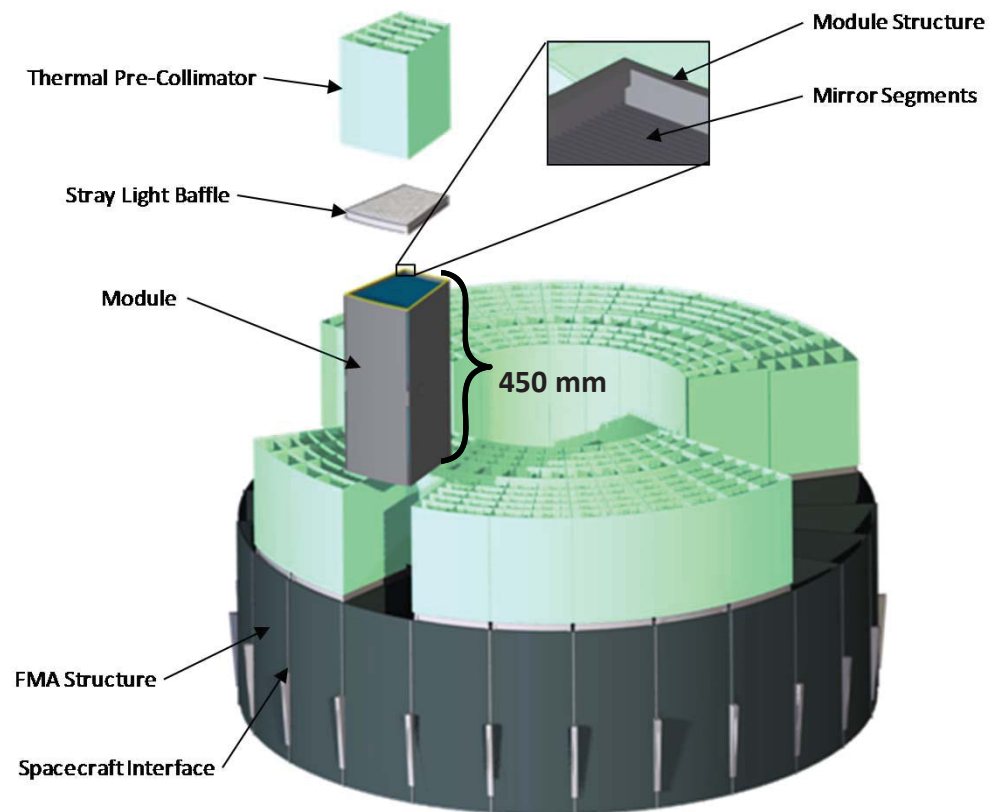


# Why X-Ray Telescopes

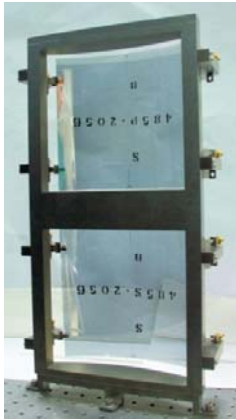
- To enable new discoveries in astrophysics by building lightweight high angular resolution X-ray optics
- Goal to achieve high resolution of Chandra with mass/cost of Suzaku
  - Low Mass- 50% Glass and 50% Structure
  - High Resolution
    - Near term - 5" to 10"
    - Long term < 1"
  - Large mirror area required for modest effective collecting area
    - 160 m<sup>2</sup> of mirror area required for 1.0 m<sup>2</sup> of effective area at 1.0 keV
- Science was identified as high priority by the Decadal Survey
- Technology scalable for any mission size
  - Sounding rocket (OGRE), Explorer (WHIMeX), Flagship (Athena)

# FMA and Module Overview

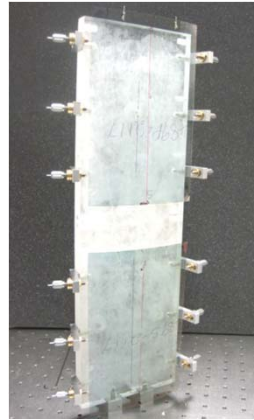
- Flight Mirror Assembly (FMA) holds dozens of modules
- Module holds hundreds of mirror segments
- Modular construction scalable to various mission sizes and objectives



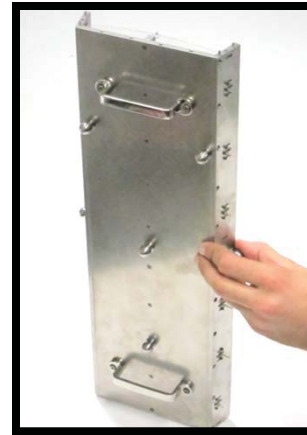
# NGXO Technology Development Modules



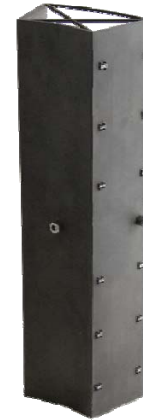
TDM 1



TDM 2



TDM 3-8



TDM 9-10



Flight-like module

- TDM progressing from a breadboard platform using Kovar to a lightweight flight-like module
- TDM9 is a bridge between TDM5 and a flight-like TRL6 demonstration module
  - Number of mirrors
  - Axial size
  - Structural Mass

# Material Options

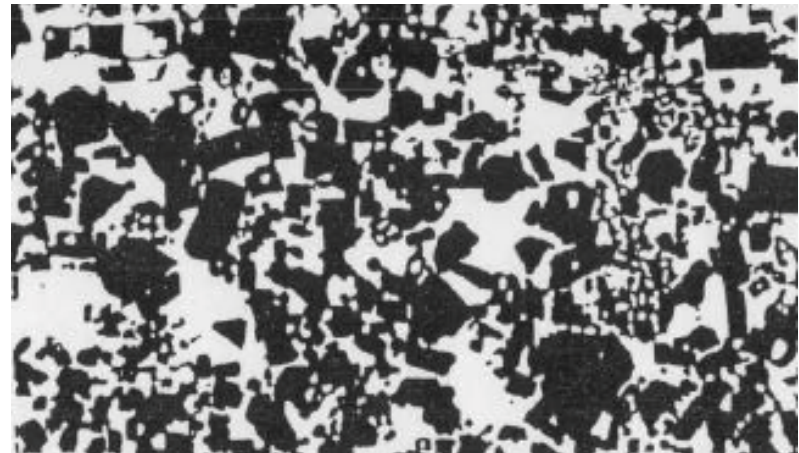
Material	Density (kg/m <sup>3</sup> )	Young's Modulus (GPa)	Specific Stiffness (10 <sup>6</sup> m <sup>2</sup> /s <sup>2</sup> )	CTE (ppm/°C)	CTE Mismatch Error (arc-sec HPD)
M55J/954-3 CFRP	1688	104	62	-0.23	9.8
AF45 Glass	2720	66	24	4.18	3.2
Alloy 42 (Fe Ni Alloy)	8110	145	18	4.48	2.7
TiSiC MMC	3930	200	51	5.90	0.6
<u>D263 Glass</u>	<u>2510</u>	<u>73</u>	<u>29</u>	<u>6.28</u>	<u>0.0</u>
T300/E-Glass composite	1700	32	19	6.28	0.0
Custom Fe Ni Alloy	8359	138	17	6.28	0.0
<b>E-60 Beryllium MMC</b>	<b>2513</b>	<b>331</b>	<b>131</b>	<b>6.68</b>	<b>0.4</b>
Kovar F15 (Fe Ni alloy)	8359	138	17	6.67	0.6
Ti6Al4V Titanium	4430	114	26	8.88	3.9
410 Series Stainless Steel	7800	200	26	9.90	5.4
Beryllium S-200FH	1850	303	164	11.4	7.7
Aluminum 6061-T6	2700	69	26	22.6	24.5

# Kovar to E-60 Be/BeO Material Comparison

- Kovar 15 has been the baseline material
  - CTE close to D263 Glass
  - Low cost material
  - Easy to machine
  - But it is very heavy
- E-60 Composite Material
  - CTE close to the D263 glass
  - High Specific Stiffness
  - High thermal conductivity
  - Low density meets mass budget

## E- Material Be/BeO Metal Matrix Composite

- E-Material is a Beryllium metal matrix composites that consists of a fine single crystal Beryllium Oxide(BeO) platelet surrounded by a continuous Beryllium(Be) matrix.
- The volume fraction of the BeO in the matrix can be altered, 20-60%, to tailor the thermal and mechanical properties
- Machining techniques
  - EDM
    - Wire and plunge
  - Diamond abrasive grinding
  - PCD machining





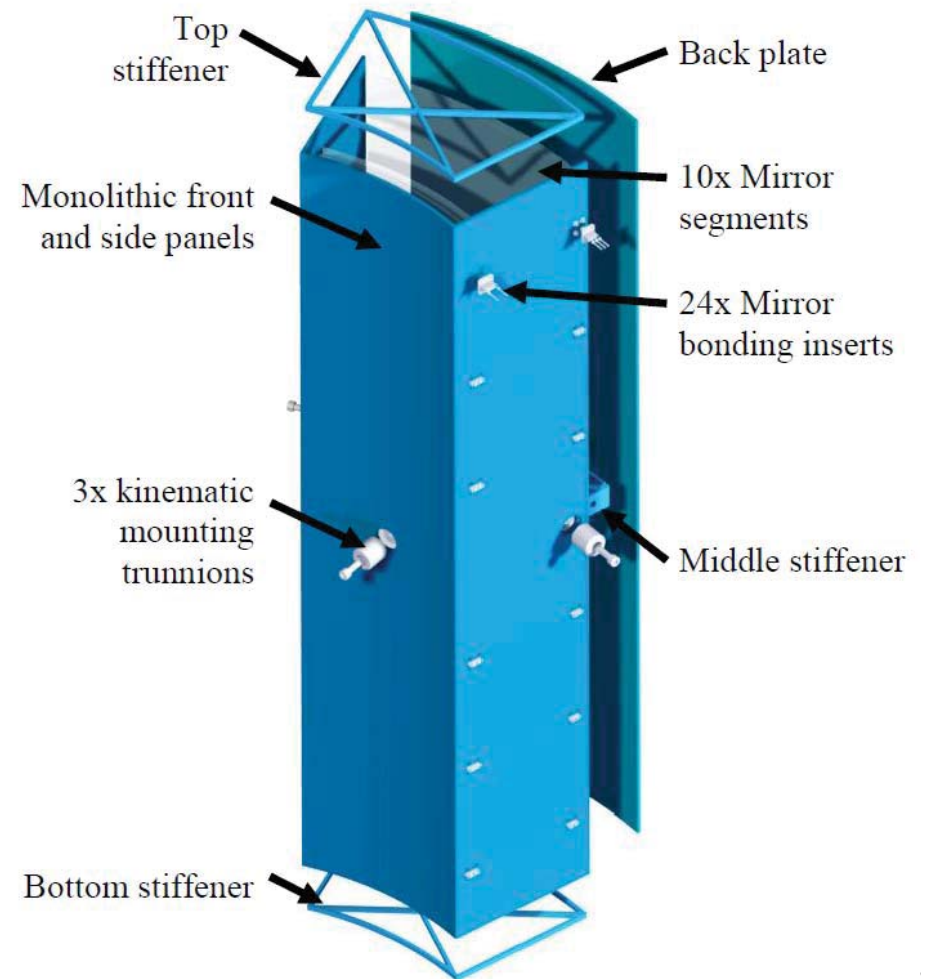
## E-60 Background

- E-Materials have been used extensively in low CTE thermal management applications
  - Iridium
  - F-16 and F-22 Avionics
- Materion has partnered with NASA to use E-60 as structural material for NGXO
  - Expands usage from electronic packaging to structural applications
  - Independent testing by NASA leads to space qualification of material and new applications



## E-60 TDM 9 Design

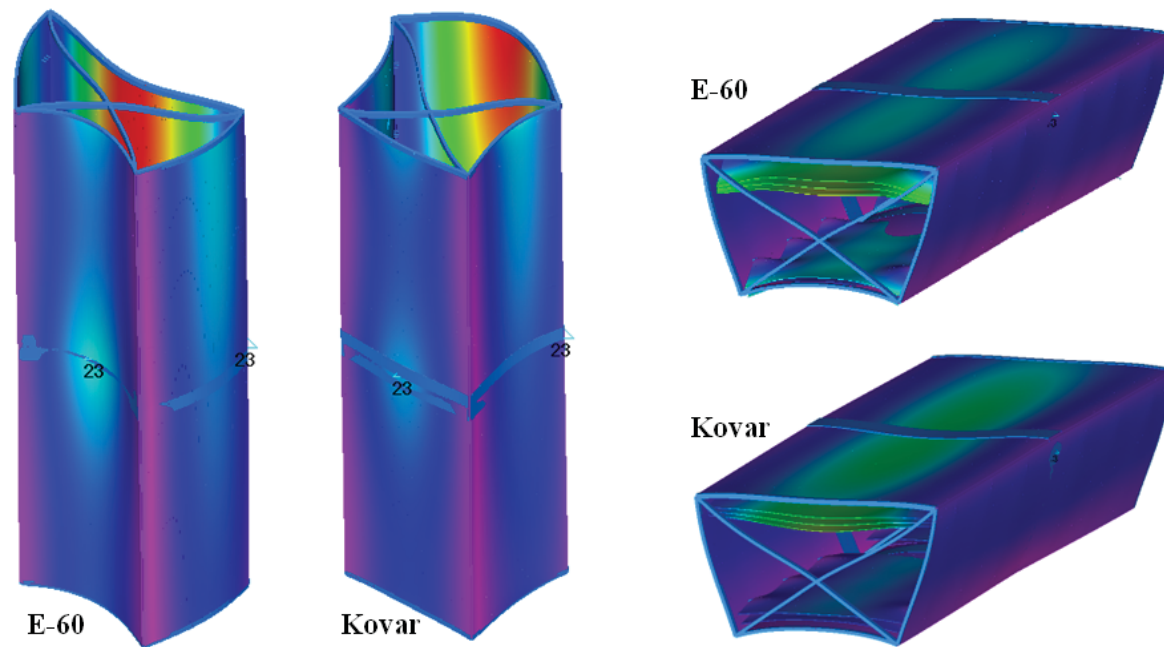
- E-60 components designed to minimize cost and risk
  - Designed for nesting components to maximize material usage
  - All E-60 parts are 2D flat patterns for wire EDM
  - Only two E-60 parts require ram EDM
- Achieves mirror to structure mass ratio of 1.5 if fully populated
- Bonded together with Hysol 9309.3 epoxy



# TDM 9 Analysis Results

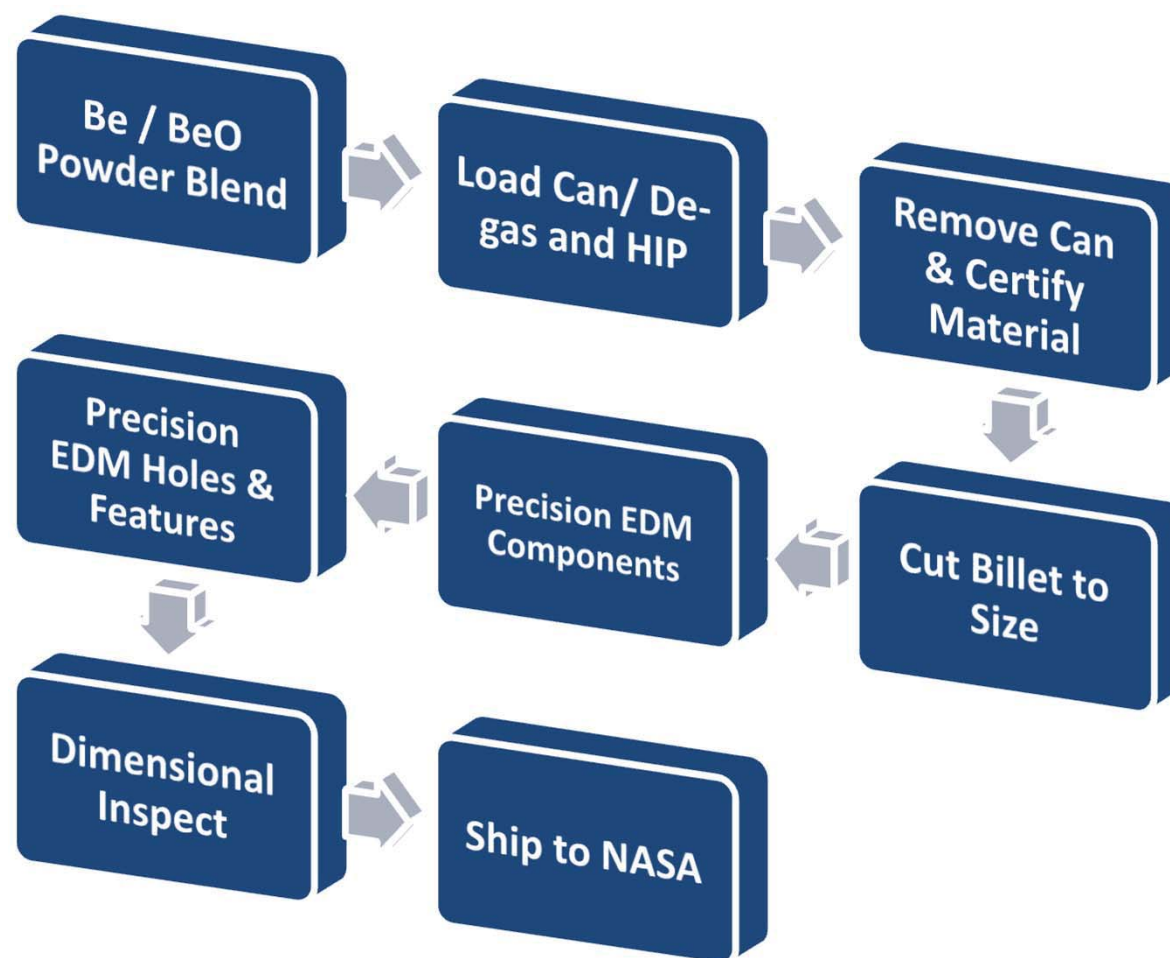
## 3.2 Analysis of next generation Technology Development Modules

In addition to being larger and lighter than the current TDMs, the next generation will also be significantly stiffer which reduces self-weight distortion, low frequency vibration amplification, and mirror/bond stress. Figure 10 illustrates the 849 Hz first mode of the E-60 TDM structure. The mode falls to 319 Hz when a Kovar structure is assumed. Figure 10 also shows the expected distortion due to gravity in the horizontal X-ray test configuration.

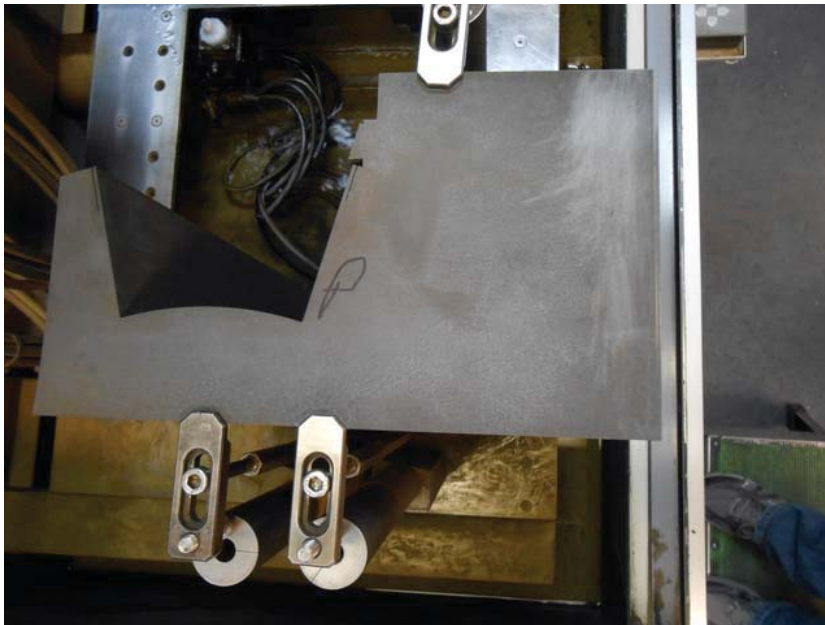


**Figure 10.** First mode of next generation TDM structure is 849 Hz when fabricated from E-60 and 319 Hz when fabricated from Kovar (left). The gravity distortion figure error in the horizontal X-ray configuration is 2.2 arc-seconds HPD with an E-60 structure and 5.8 arc-seconds HPD with a Kovar structure (right).

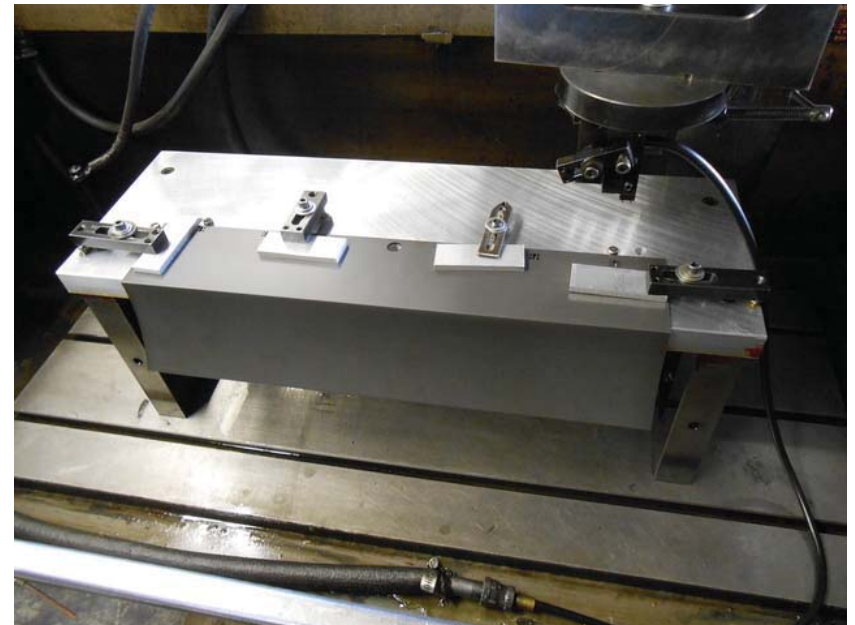
## E-60 TDM9 Manufacturing Flow



## Billet EDM



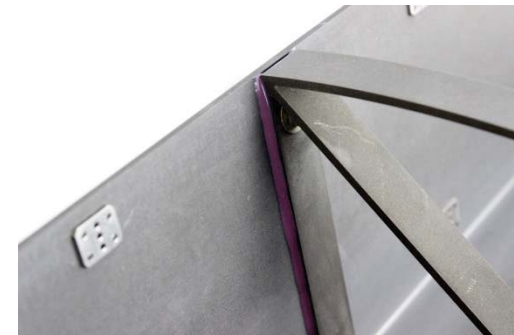
Main Shell EDM Setup  
(Wire EDM)



Mounting Feature EDM Setup  
(Plunge EDM)

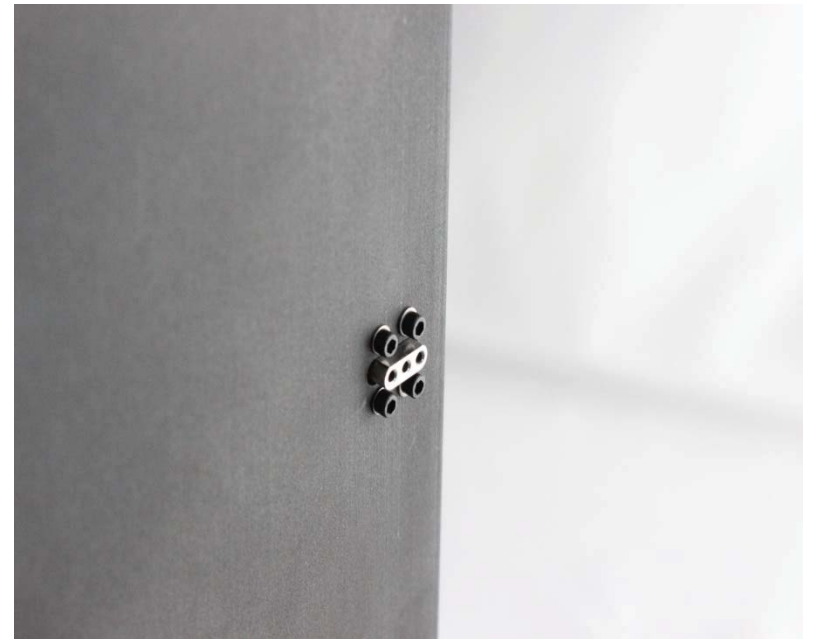
## TDM 9 Fabrication

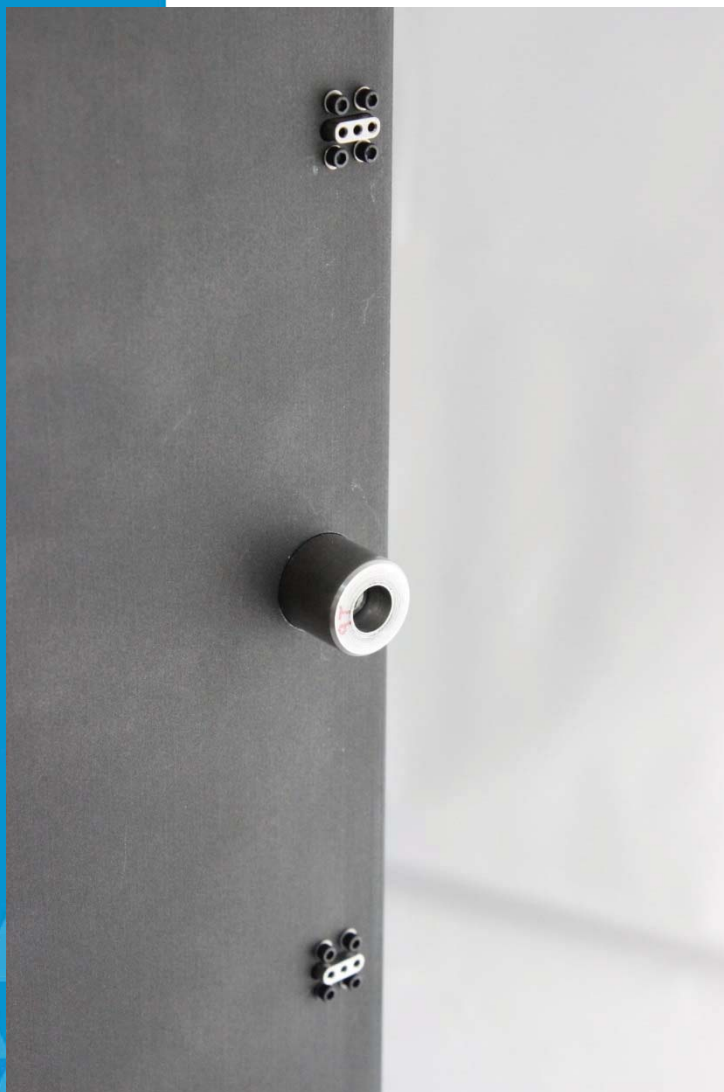
- E-60 block fab
- Approx 16 weeks lead time for E-60 billet and another 12 weeks to EDM components
- Approx module cost is \$30k-\$40k
- EDM lessons learned
  - Sharp external radii issue
  - Wire breaking issues due to height of block, special wire needed
  - The taller the module, the worse the wire bow leading to stiffener fit issue





# TDM9 Bonded Inserts





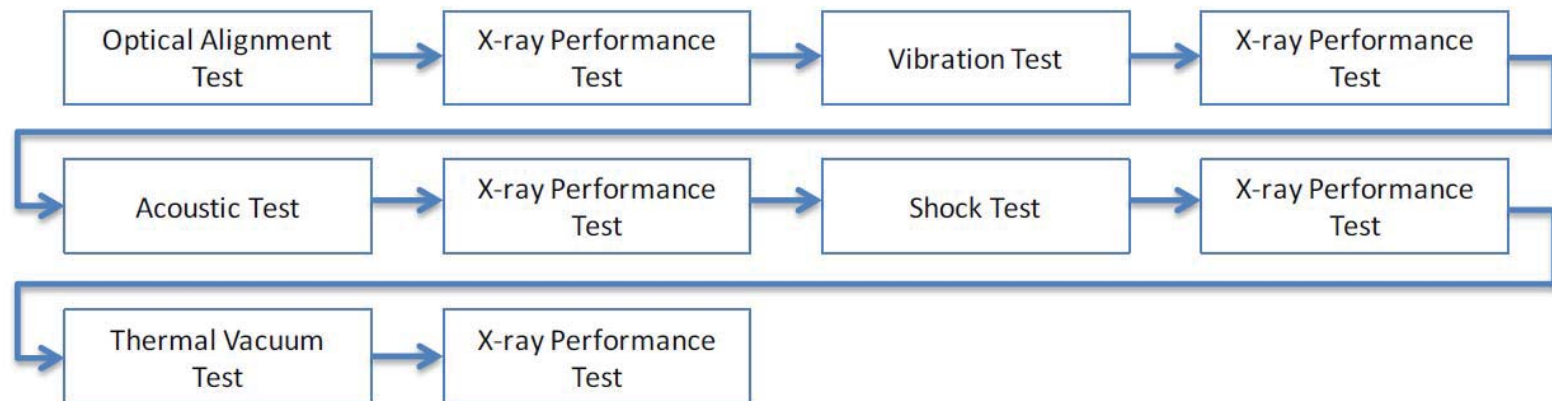


# TDM9 Bonded Bulkheads



## TDM 9 Test Flow

- Test to generic flight mission requirements
  - 6.8 G rms random vibration
  - 143.3 dB OASPL acoustic
  - 3,000g pyro-shock- Separation Load Test
  - 0°C-40°C thermal vacuum cycling
- Pre and post x-ray performance testing to verify stability



## Conclusion

- E-60 is a viable structural material for X-ray telescope modules
  - CTE very close to D263 glass which minimizes distortion due to thermal loading
  - May be able to modify Be/BeO ratio to make CTE a closer match
  - Low density meets mass target
  - Lots of lessons learned on EDM process
- Future work
  - Test and verify TDM 9 Module
  - Material characterization leading to space certification
  - Mission specific design and testing (eg OGRE)